Astrometeric Science with SIM PlanetQuest

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for

Stephen Unwin

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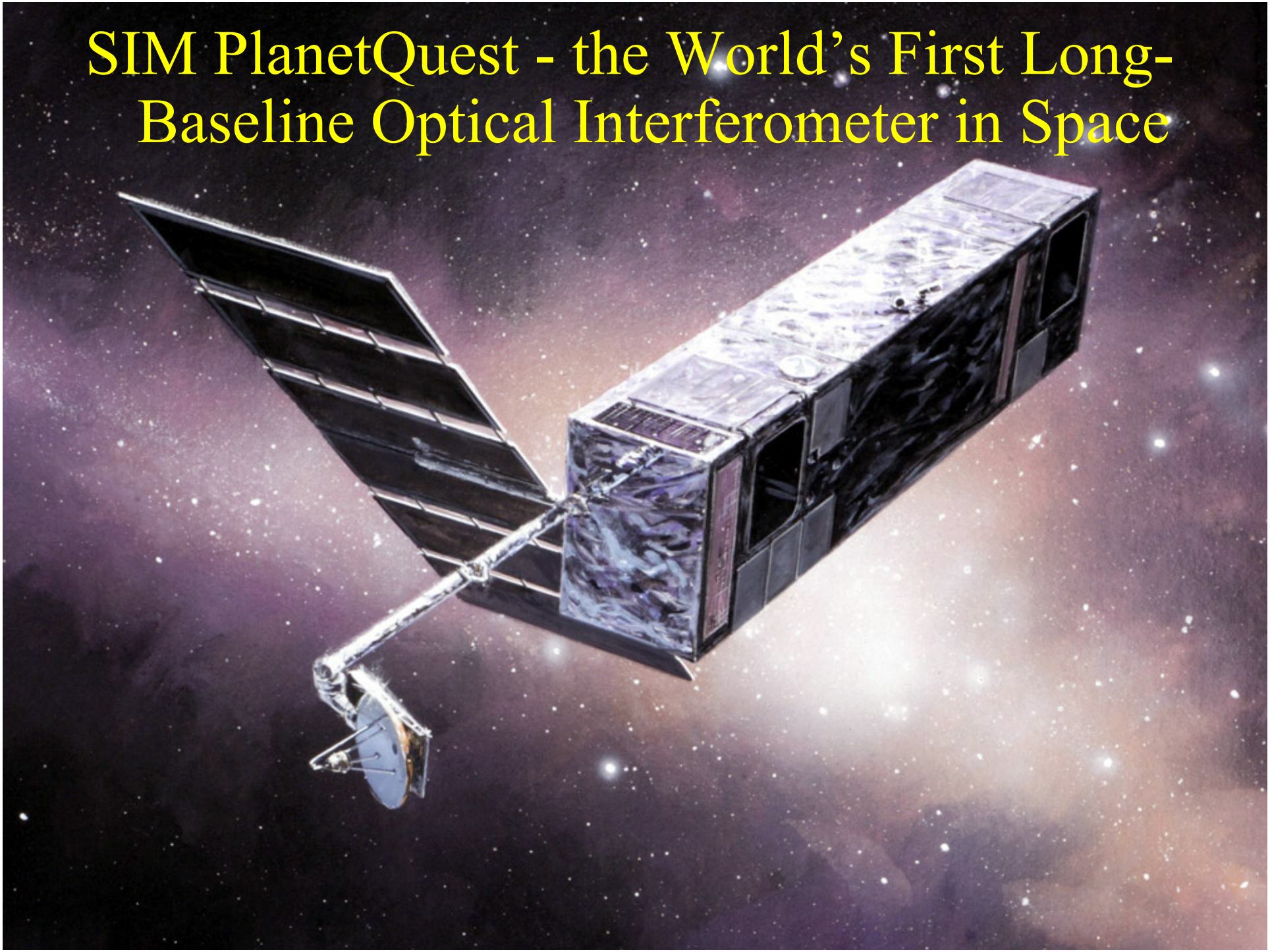
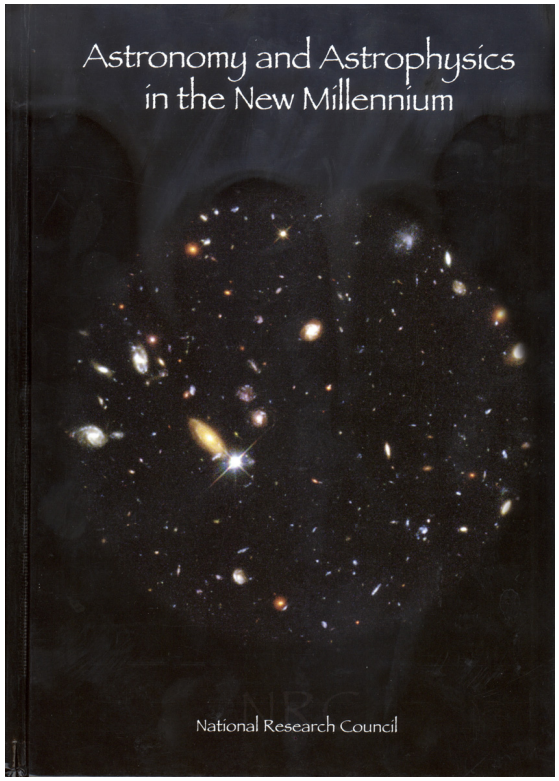
SIM PlanetQuest - the World's First Long-Baseline Optical Interferometer in Space



National Academy of Sciences / NRC endorses SIM PlanetQuest

- Decadal (Bahcall) Review endorses SIM (1991)
  - *"… would permit definitive searches for planets around nearby stars"*
  - *"… trigonometric distances throughout the galaxy"*
  - *"… would demonstrate the technology required for future missions"*
- Decadal (McKee & Taylor) Review (2001)
  - *"…reaffirms the 1991 NRC Committee by endorsing the completion of AIM [now called SIM]"*
  - *"… enable the discovery of planets much more similar to Earth in mass and orbit than those detectable now"*
  - *"…survey the Milky Way 1000 times more accurately than is possible now"*
- CAA reaffirms scientific importance of SIM (2002)
  - *"The CAA reaffirms the scientific excitement of the 2001 AASC for the important new planet-finding narrow-angle science capability of SIM."*

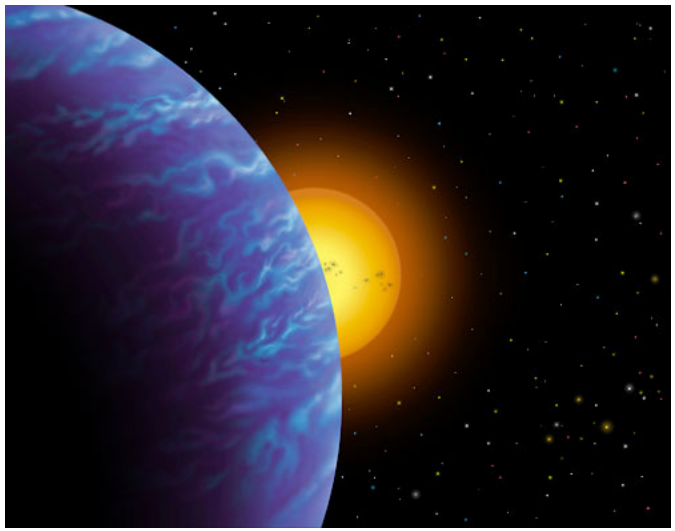


2001 NRC Decadal Review

SIM Planet Search

What We Don't Know

- Are planetary systems like our own common?
- What is the distribution of planetary masses?
  - **Only astrometry measures planet masses unambiguously**
- Are there low-mass planets in 'habitable zone' ?



A Broad Survey for Planets

- Is our solar system unusual?
- What is the range of planetary system architectures?
- Sample 2,000 stars within ~25 pc with sensitivity <<Jupiter mass

A Deep Search for Earths

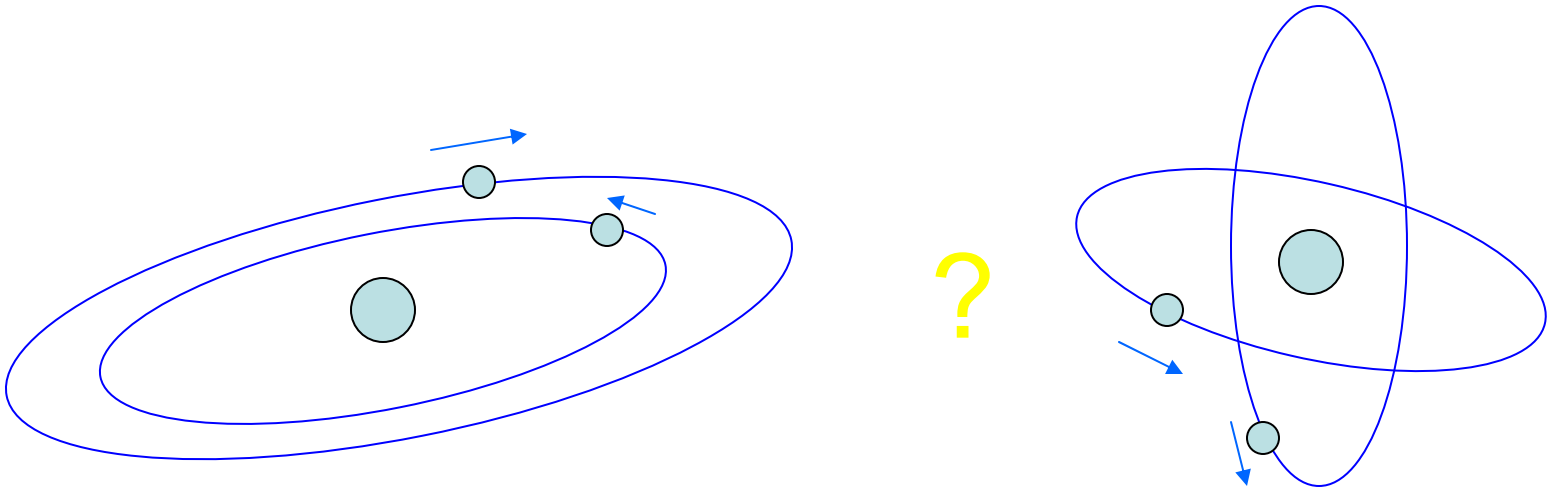
- Are there Earth-like (rocky) planets orbiting the nearest stars?
- Focus on ~250 stars like the Sun (F, G, K) within 10 pc
- Detection limit of ~3 M_e at 10 pc
- Sensitivity limit of ~1 M_e at 3 pc

Evolution of Planets

- How do systems evolve?
- Is the evolution conducive to the formation of Earth-like planets in stable orbits?
- Do multiple Jupiters form and only a few (or none) survive?

Planetary System Architectures & Diversity

- Comprehensive survey of 2000 stars to probe Jovian/Neptunian planets (metalicity, debris disks, binary systems)
- Search for planets around stars not probed by any other technique (O, B, A, early F, white dwarfs).
- Uniquely probe for planets around young stars and thus provide insight into evolution of planetary systems
- Measure planet masses, eccentricities, orbital direction and mutual orbital inclinations of multiple planet systems

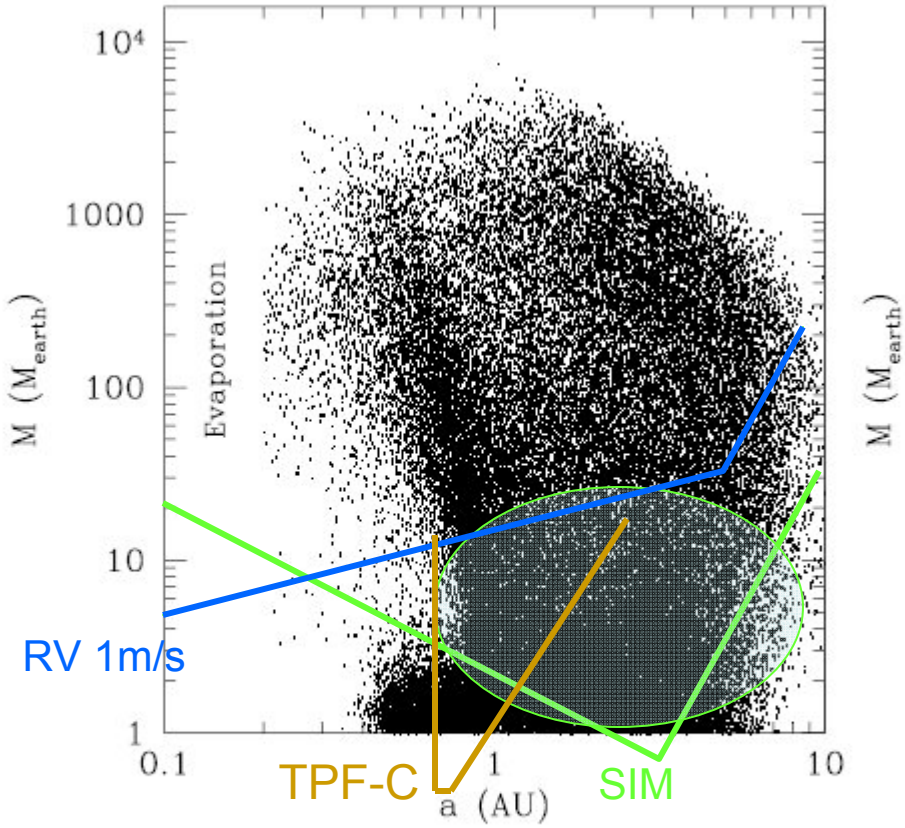


SIM Search for 1~10 M_{earth} Planets Around Nearby Stars

With the discovery of ~200 planets outside our solar system, this has provided data to constrain models of planetary system formation.

All of these models predict that the Jupiter to Neptune sized planets discovered to date are the tip of the iceberg.

SIM is uniquely position to detect the bulk of these planets, in the 1~10 Mearth 0.4~6.0AU range.

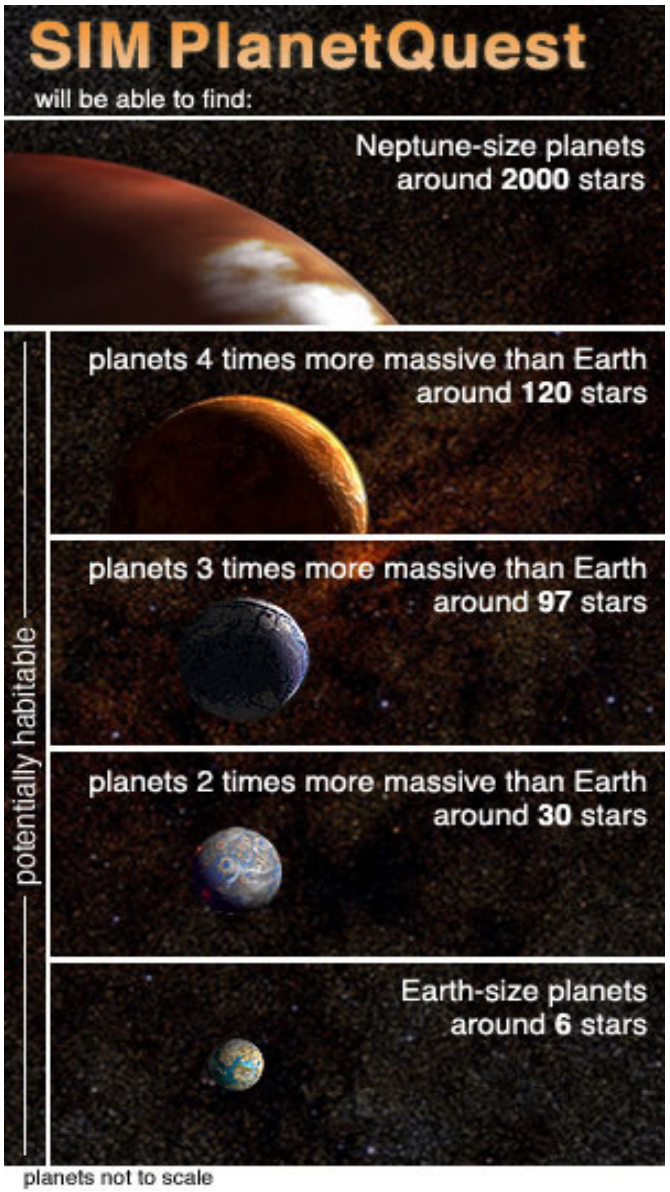


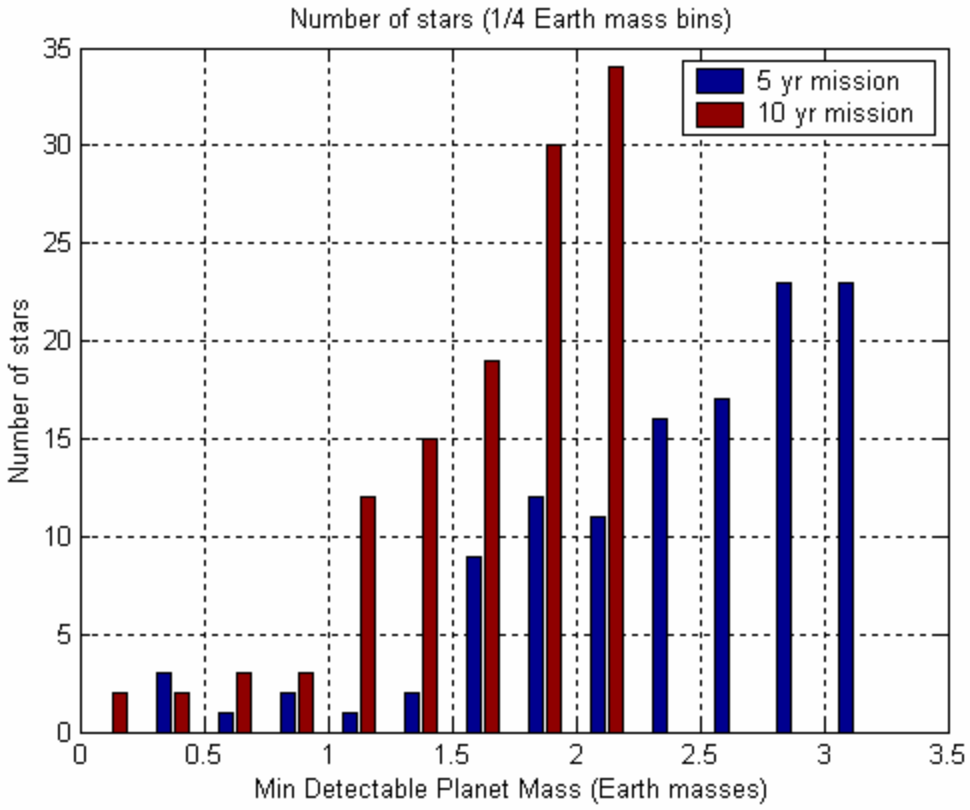
$\alpha = 210^{-3}$, $f_I = 0.01$

$\Longrightarrow$ the majority of embryos do not become giants

Benz, et al. IAU Coll 200, 2005, p 1.

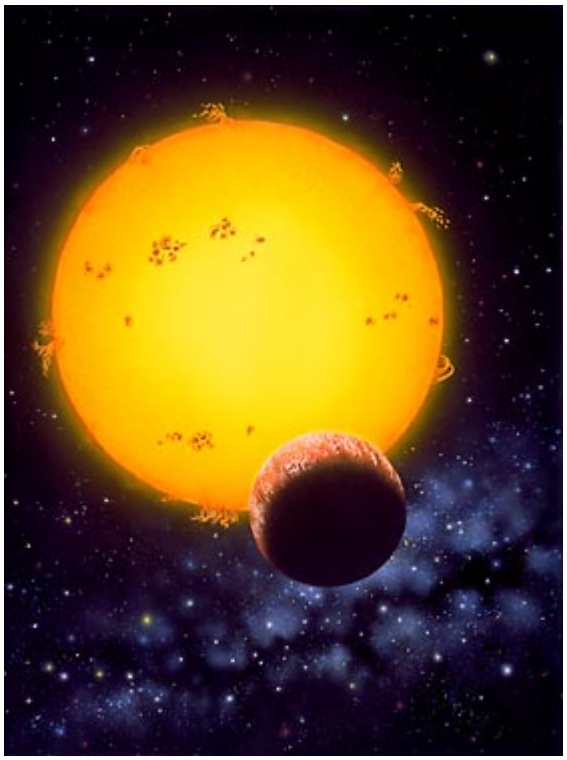
Deep Search of 120 nearby stars





Planets around Young Stars

- What fraction of young stars have gas-giant planets?
  - Only SIM astrometry can find planets around young stars since active stellar atmospheres and rapid rotation preclude radial velocity or transit searches
- Do gas-giant planets form at the "water-condensation" line?
  - SIM will survey ~200 stars to a level adequate to find Jovian or smaller planets on orbits <1 AU to >5 AU around stars from 25-150 pc
- Does the incidence, distribution, and orbital parameters of planets change with age and protostellar disk mass?
  - Study of clusters with ages spanning 1-100 Myr to test orbital migration theories
  - Correlate with Spitzer results on disks (at 4-24 μm)
- Where, when, and how do terrestrial planets form ?
  - Understand the formation and orbital migration mechanisms of the giant planets



SIM PlanetQuest Science Team

Key Science Projects

Dr. Geoffrey Marcy	U. California, Berkeley	Planetary Systems
Dr. Michael Shao	NASA/JPL	Extrasolar Planets
Dr. Charles Beichman	NASA/JPL	Young Planetary Systems and Stars
Dr. Andrew Gould	Ohio State University	Astrometric Micro-Lensing
Dr. Edward Shaya	U. Maryland	Dynamic Observations of Galaxies
Dr. Kenneth Johnston	U.S. Naval Observatory	Reference Frame-Tie Objects
Dr. Brian Chaboyer	Dartmouth College	Population II Distances & Globular Clusters Ages
Dr. Todd Henry	Georgia State University	Stellar Mass-Luminosity Relation
Dr. Steven Majewski	University of Virginia	Measuring the Milky Way
Dr. Ann Wehrle	MSC/Caltech	Active Galactic Nuclei

Mission Scientists

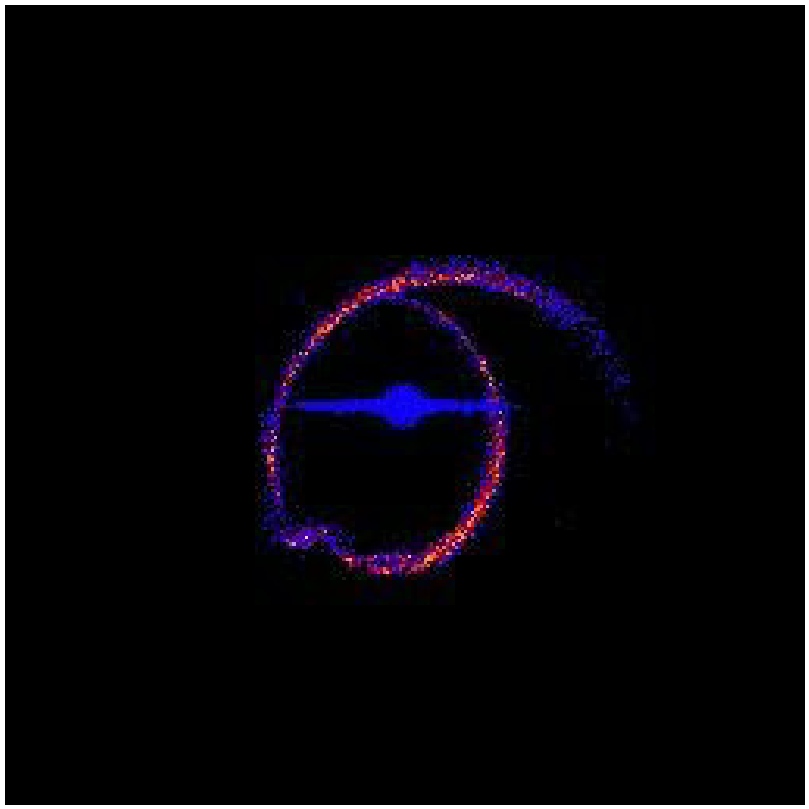
Dr. Guy Worthey	Washington State University	Education & Public Outreach Scientist
Dr. Andreas Quirrenbach	U. California, San Diego	Data Scientist
Dr. Stuart Shaklan	NASA/JPL	Instrument Scientist
Dr. Shrinivas Kulkarni	Caltech	Interdisciplinary Scientist
Dr. Ronald Allen	Space Telescope Science Inst.	Synthesis Imaging Scientist

Only Principal Investigators listed. Including co-investigators the SIM Science Team has 86 members.

Dark Halo of our Galaxy

- 'Dwarf spheroidal' galaxy orbits the Milky Way
- Gravitational forces pull out 'tidal tails' of stars
- The orbits of these tails trace the past history of the dwarf
- They also trace the mass distribution of the Milky Way
- They are dynamically 'cold'

- SIM provides:
  - Astrometric motions of stars out to > 20 kpc
- Why SIM?
  - Need astrometric accuracy
  - *and* sensitivity



Simulation by Kathryn Johnston (Wesleyan University)

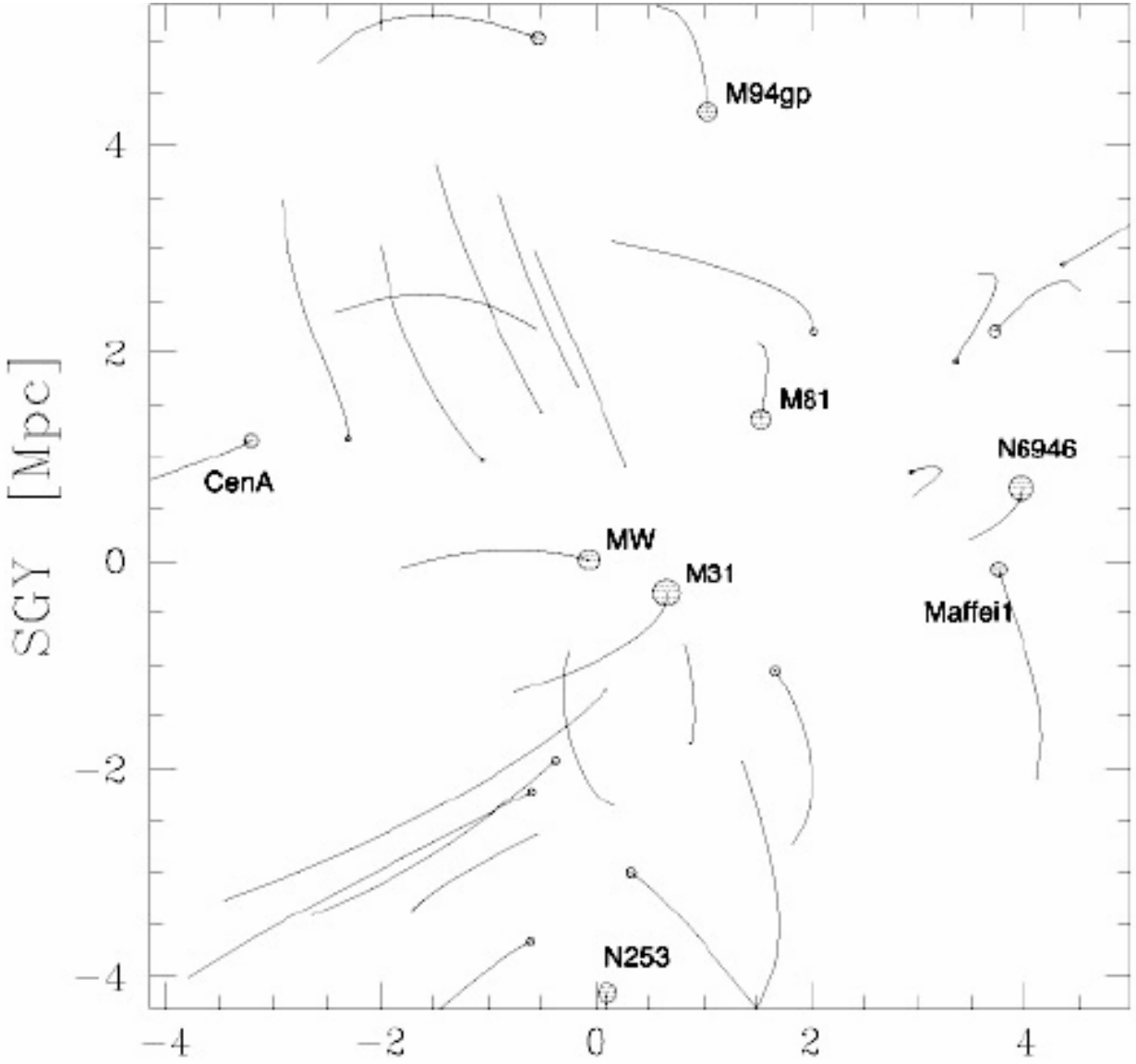
Dynamics of Galaxy Groups within 5 Mpc

Simulation from dynamical model

- Can't verify model because only 1-D velocity info is available (RV)

SIM will provide critical data for improving the models

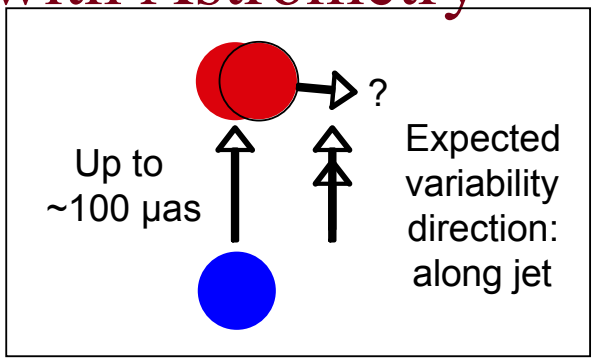
- SIM will measure current 2-D velocities across the sky
- Models will then sample the full 6-D phase space

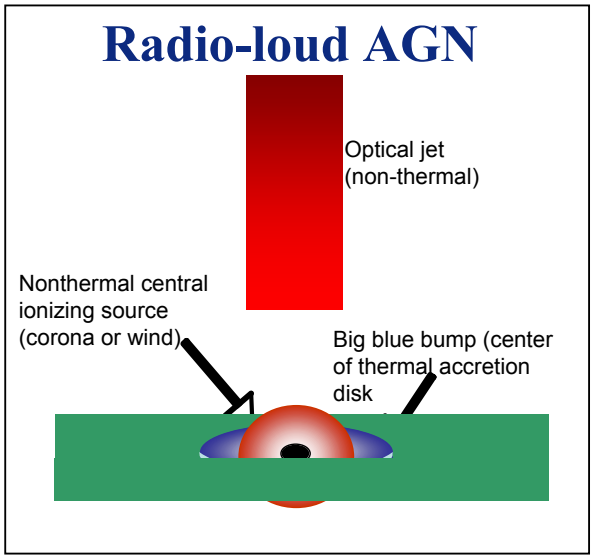


Simulated 'time-lapse' photo of 30 galaxies closest to our Milky Way (1-billion year exposure)

Probing Active Galactic Nuclei with Astrometry

1. Does the most compact non-thermal optical emission from an AGN come from an accretion disk or from a relativistic jet?
2. Do the cores of galaxies harbor binary supermassive black holes remaining from galaxy mergers ?
3. Is the separation of the radio core and optical photocenter of the quasars used for the reference frame tie stable? Or does it change on the timescales of their photometric variability?

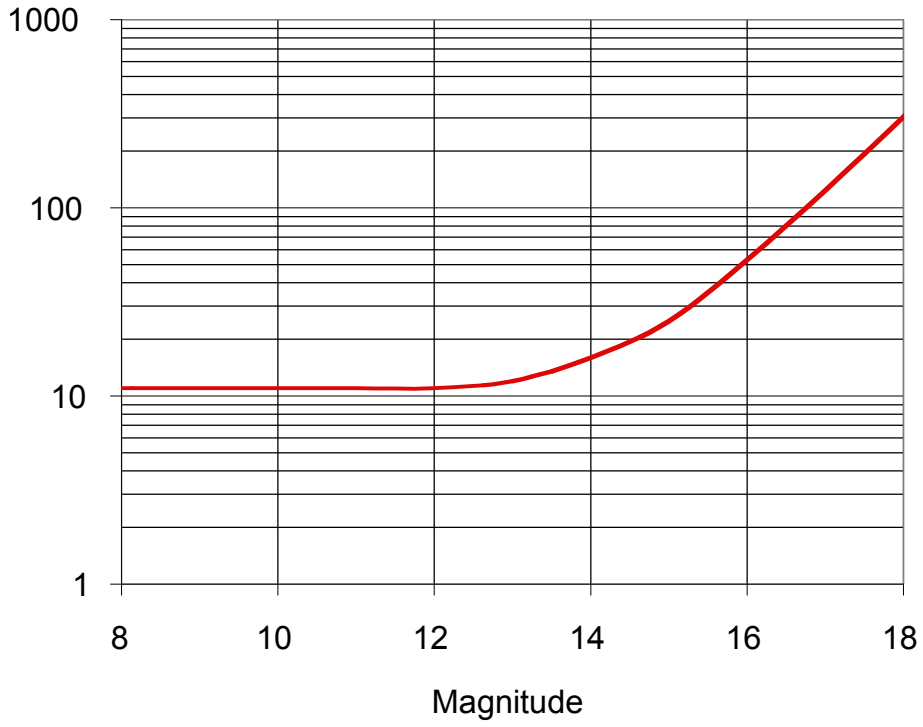




- SIM measurements:
  - Astrometric shifts as a function of wavelength
  - *Flexible scheduling* - coordinated campaigns of flare outbursts with VLBI, X-ray telescopes
  - Relative astrometry between QSO and reference stars (or other QSOs)
  - Global astrometry: motion of QSOs relative to global reference frame
    - Departures from Hubble flow: $z = 0.1$, V = 10,000 km/s → 6 μas / yr

Snapshot Observing Mode: "Astrometry for the masses"

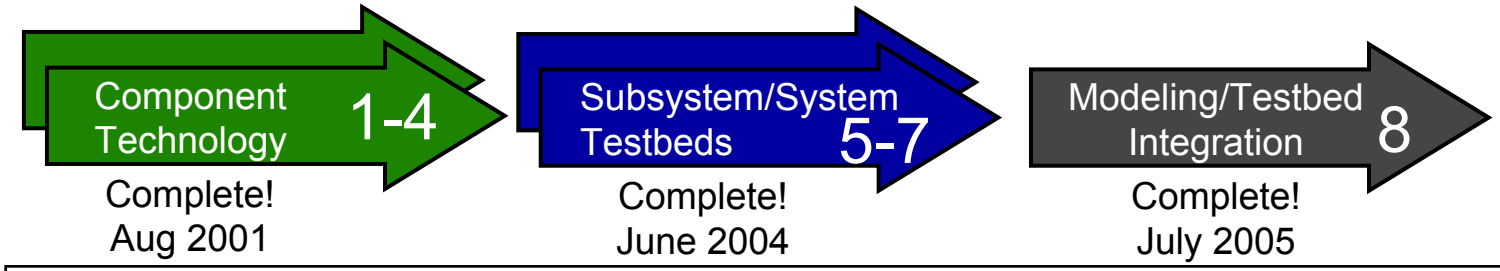
- *You don't need to be a black-belt astrometrist to use this mode*
- Mode will deliver the "5 standard astrometric parameters":
  - Position (RA, dec), parallax, proper motion (RA, dec)
  - Accuracy ~10-50 μas, and magnitude range V ~ 8-17
- Large number of targets (total ~20,000)
- Available though the *Guest Observer Program* - about 1/4 of SIM time



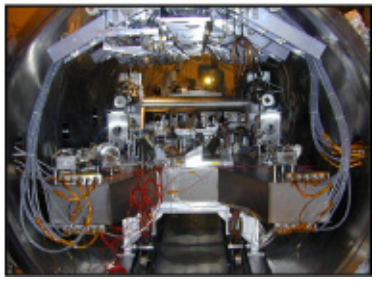
10 minutes per target, spread over 2 years; 5 visits x 2 coordinates

SIM Technology Development is Complete !

- Technology plan laid out in mid-1990s
- NASA HQ and SIM project laid out 8 Key Technology Gates in 2001
  - 4 Gates prior to Phase B start; 4 more Gates prior to Phase C/D start
- All 8 Technology Gates were completed on schedule with external peer review
- External reviewers & NASA sponsor have concurred: *Technology is complete*
- NASA & Project have established 9 Engineering milestones for Phase B/C/D



Goal-Level Performance & TRL-6 Maturity Has Been Demonstrated


MAM


KITE

Subsystem-level Testbeds

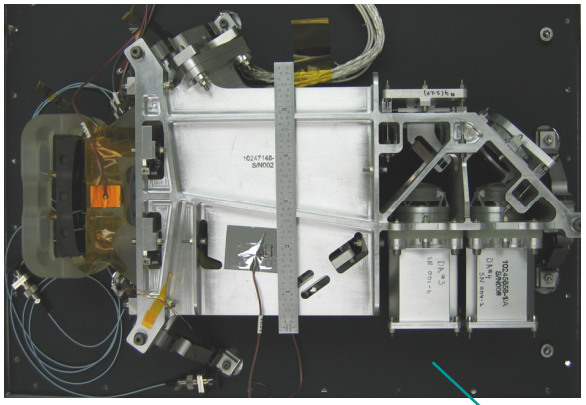

STB-3

System-level Testbed

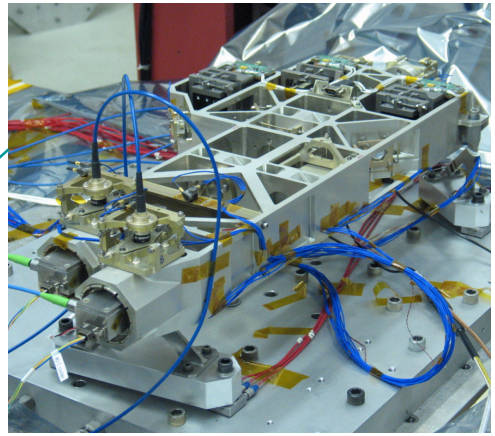
TOM-3

Modeling/Testbed Integration

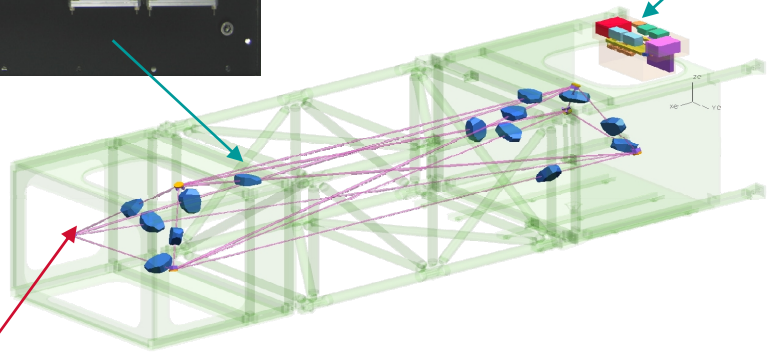
SIM Hardware, Tested for Flight

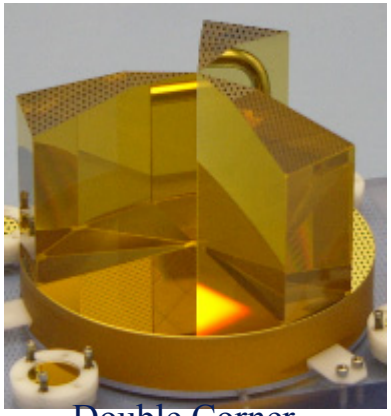


External Metrology Launcher



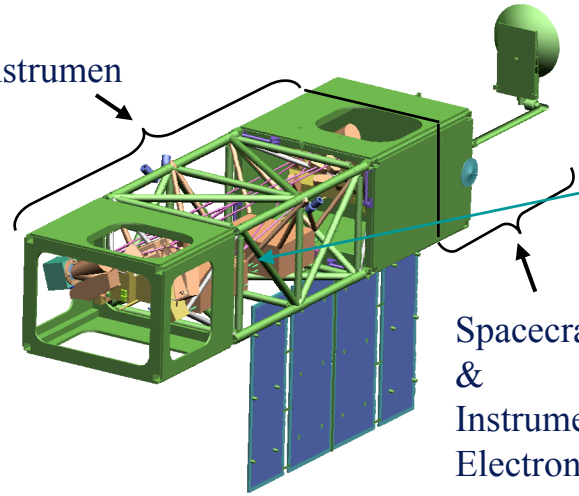
Metrology Source



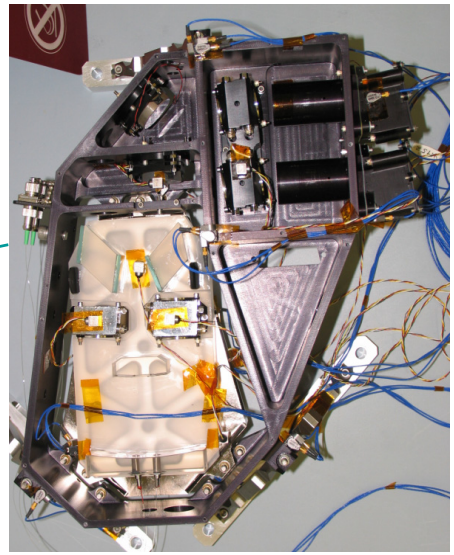


Double Corner Cube

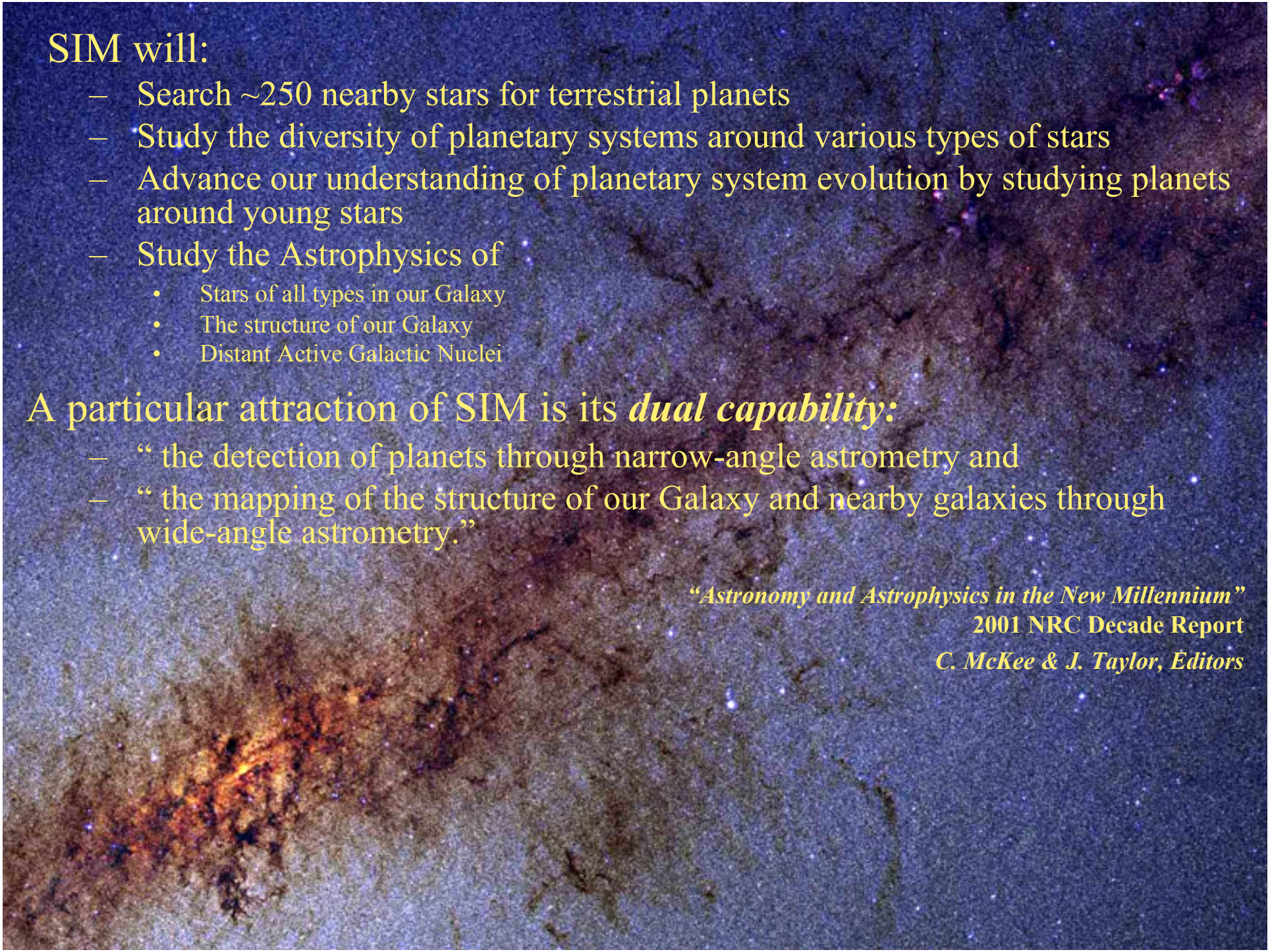
Instrument



Spacecraft & Instrument Electronics



Internal Metrology Launcher



SIM will:

- Search ~250 nearby stars for terrestrial planets
- Study the diversity of planetary systems around various types of stars
- Advance our understanding of planetary system evolution by studying planets around young stars
- Study the Astrophysics of
  - Stars of all types in our Galaxy
  - The structure of our Galaxy
  - Distant Active Galactic Nuclei

A particular attraction of SIM is its ***dual capability:***

- " the detection of planets through narrow-angle astrometry and
- " the mapping of the structure of our Galaxy and nearby galaxies through wide-angle astrometry."

"Astronomy and Astrophysics in the New Millennium"
2001 NRC Decade Report
C. McKee & J. Taylor, Editors